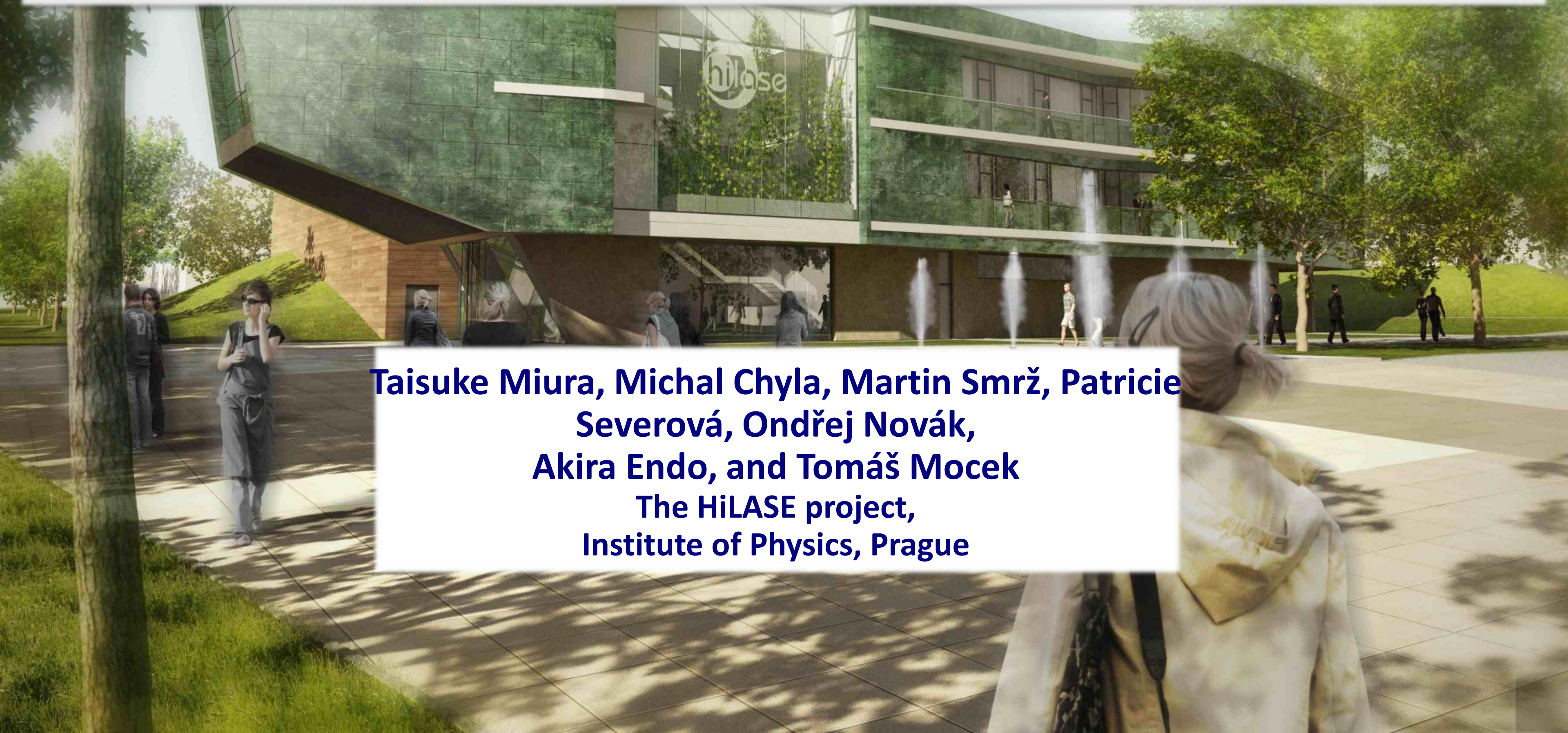
High Brightness, High-average Power Picosecond Thin Disc Laser Program to Specific Requirements from Short Wavelength Light Sources (S28)



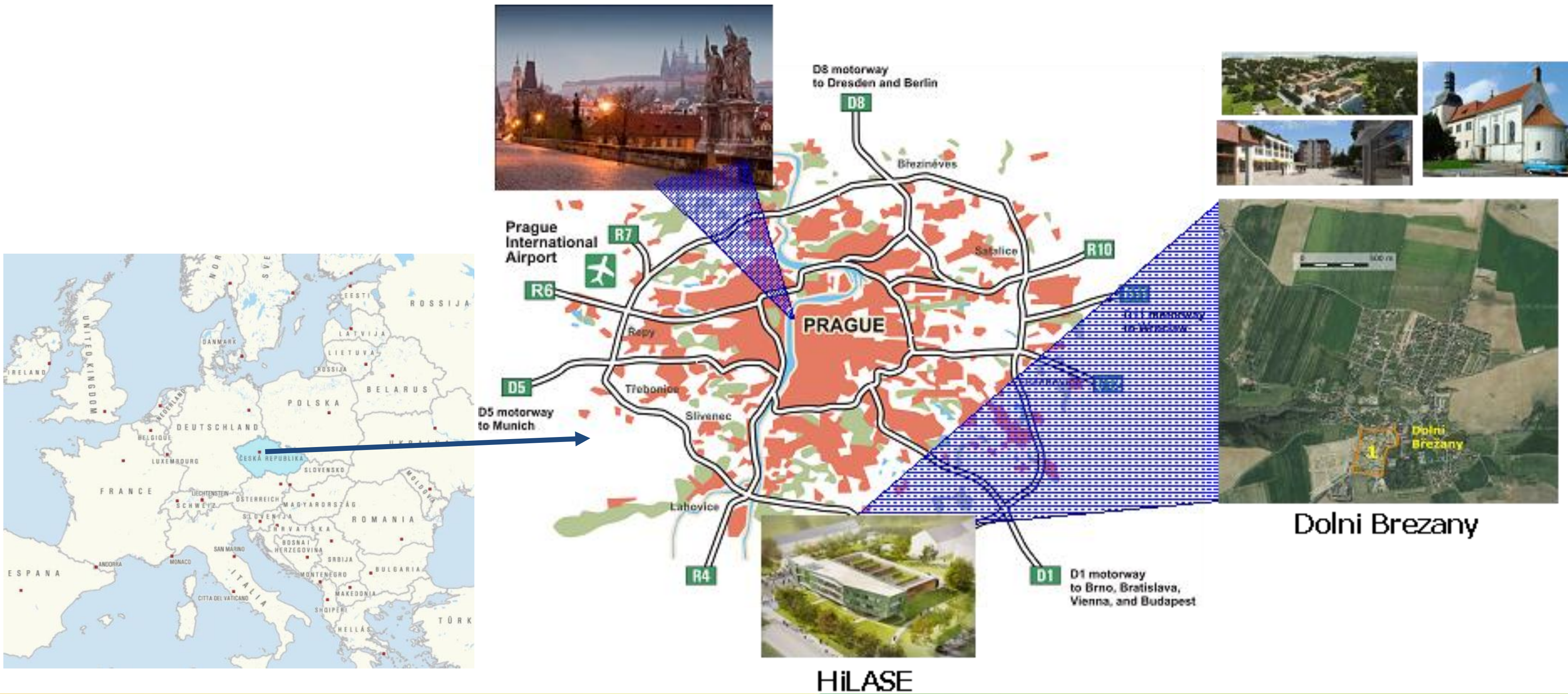
Taisuke Miura, Michal Chyla, Martin Smrž, Patricie Severová, Ondřej Novák, Akira Endo, and Tomáš Mocek
The HiLASE project, Institute of Physics, Prague

Overview of The HiLASE Project

- HiLASE: High average power pulsed LASErs
- European project on strategic development of advanced solid-state laser technologies based on diode pumping (thin-disk laser, multi-slab laser)
- Potential for novel industrial applications using pulsed, high-energy & high-average power DPSSL
- Motivated by strong need for head-start laser technology development & prototyping for the next generation of high-energy, large scale laser facilities (ELI Beamlines, HiPER)
- Implementation phase: 09/2011- 08/2015
- Application phase: 2015-

Location of The HiLASE Project

- Area of future **R&D centres** south of Prague city, enjoyable surroundings
- Synergy with **ELI** (on site) and biotechnology center **BIOCEV** (at 2 km distance)
- Fast connection (20 min.) to Ruzyne international airport



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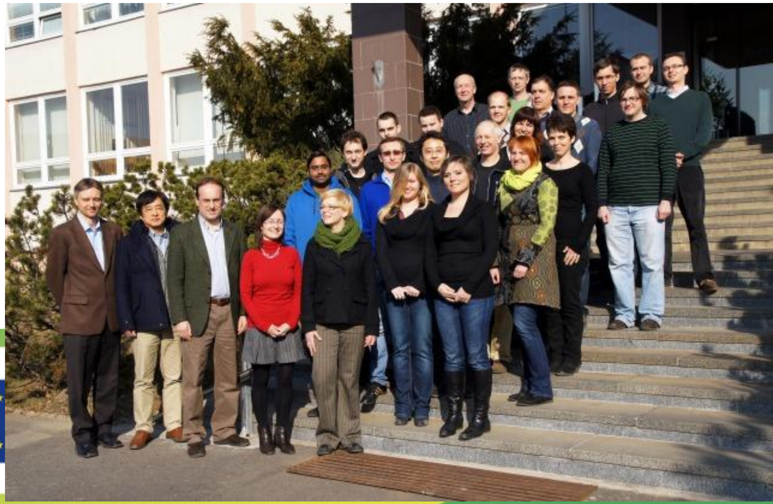
HiLASE team

PM	T. Mocek
RP-1	A. Endo, T. Miura, M. Smrž, O. Novák, M. Chyla, P. Severová, Shiva Shankar. N
RP-2	A. Lucianetti, M. Divoký, O. Slezák, M. Sawicka, P. Sikocinski, V. Jambunathan, J. Pilař, V. Kmetík
RP-3	D. Rostohar, J. Vanda, L. Gemini, R. Švábek, Ch. Liberatore
Technical sup.	M. Řeháková, V. Červenka, L. Švandrlík, J. Kadlec, H. Vohníková
Admin. sup.	L. Masopust, I. Vrbová, J. Svojšová, V. Svoboda, M. Vanková, J. Kavanová, J. Černý, R. Tůma, R. Kozáková, R. Karešová

10 / 2012 36 staff

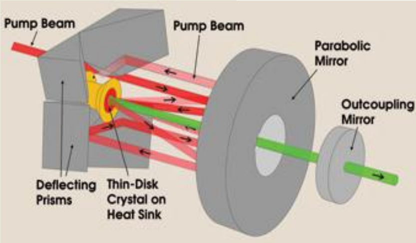
08 / 2015 55 FTE

50% of our research staff is from abroad.

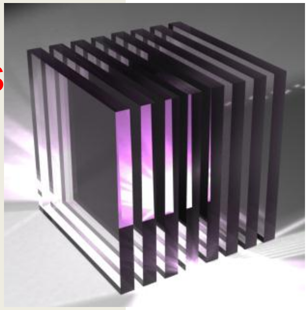


Project Activities of the HiLASE

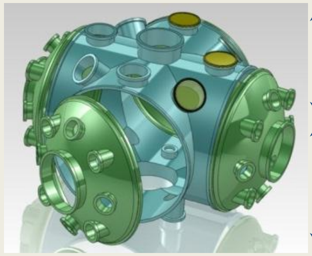
- HiLASE Research Program 1 (Thin disk laser)
  - Development of multi-J, kW class ps thin-disk laser system
  - Mainly focused on medial and industrial applications
  - Three beam lines with different beam parameters



- HiLASE Research Program 2 (Multi slab laser)
  - Development of 100 J / 10 Hz cryogenically cooled multi-slab ns DPSSL system scalable to kJ level
  - Applications: Laser-induced damage threshold test (LIDT), Laser peening, Pumping source of OPCPA in the ELI project



- HiLASE Research Program 3 (Applications)
  - Using RA1 and RA2 lasers for industrial applications
  - Applications:
    - EUV(13.5 nm) and Beyond-EUV(6.x nm) light source based on laser-induced plasma,
    - Short pulse X-ray sources based on laser-Compton scattering for biomedical imaging
    - LIDT and Laser peening



Beam Lines of RP1

hilase

Beam Line-A

- Oscillator
- Pulse stretcher
- Regenerative amplifier
- Booster amplifier
- Pulse compressor
- **1 J, 1-2 ps, 1 kHz**

Beam Line-B

- Oscillator
- Pulse stretcher
- Regenerative amplifier
- Ring amplifier
- Pulse compressor
- **0.5 J, 1-2 ps, 1 kHz**

500W, High energy

Beam Line-C

- Oscillator
- Pulse stretcher
- Regenerative amplifier
- Pulse compressor
- **5 mJ, 1-2ps, 100 kHz**

500W, High rep. rate

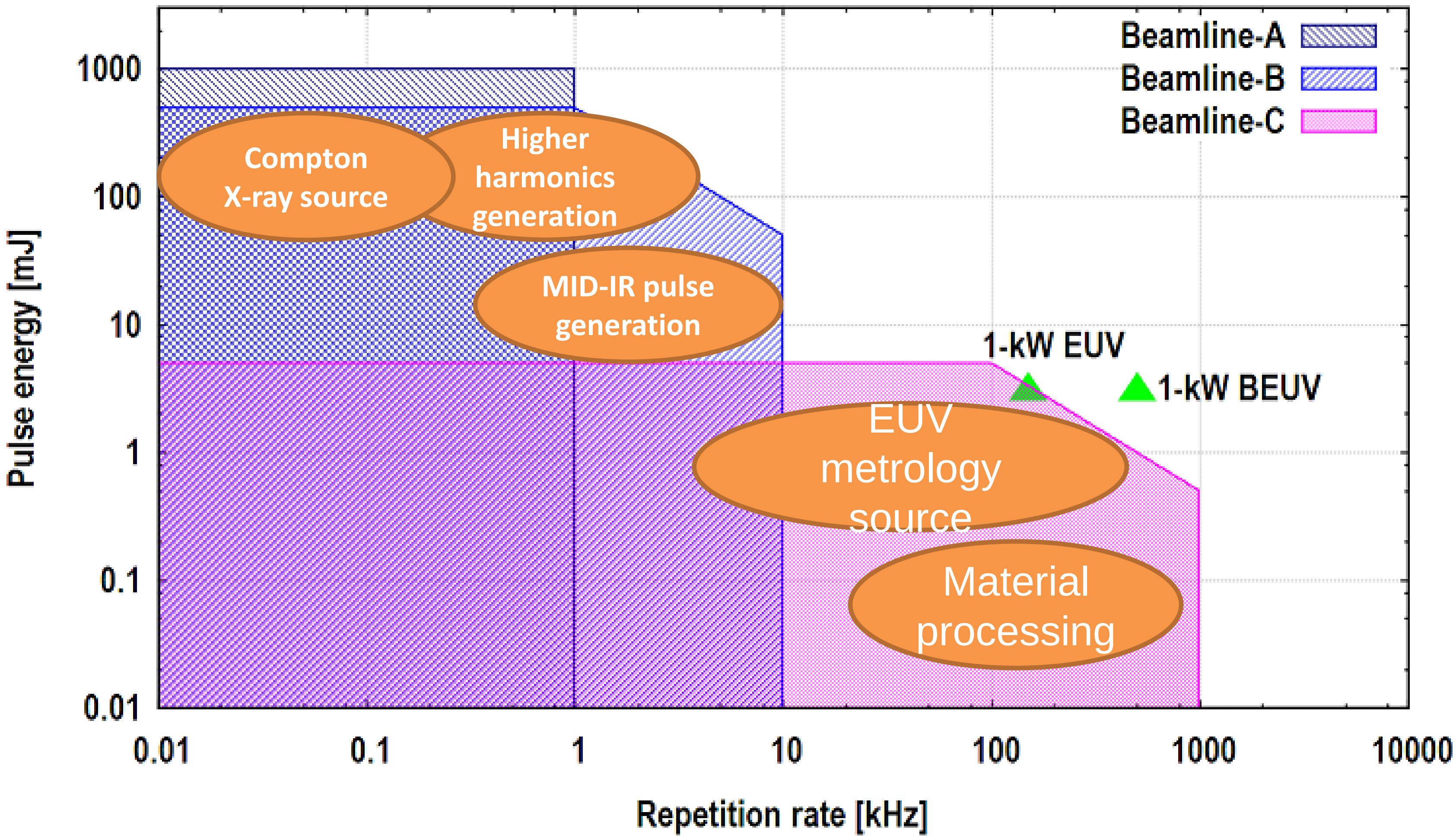
Priority issues of beam line B & C

- High beam quality
- High reliability
- Small footprint
- Cost effective

Sub-contract

In-house development

Industrial and Medical Applications Using High Energy Picosecond Pulse



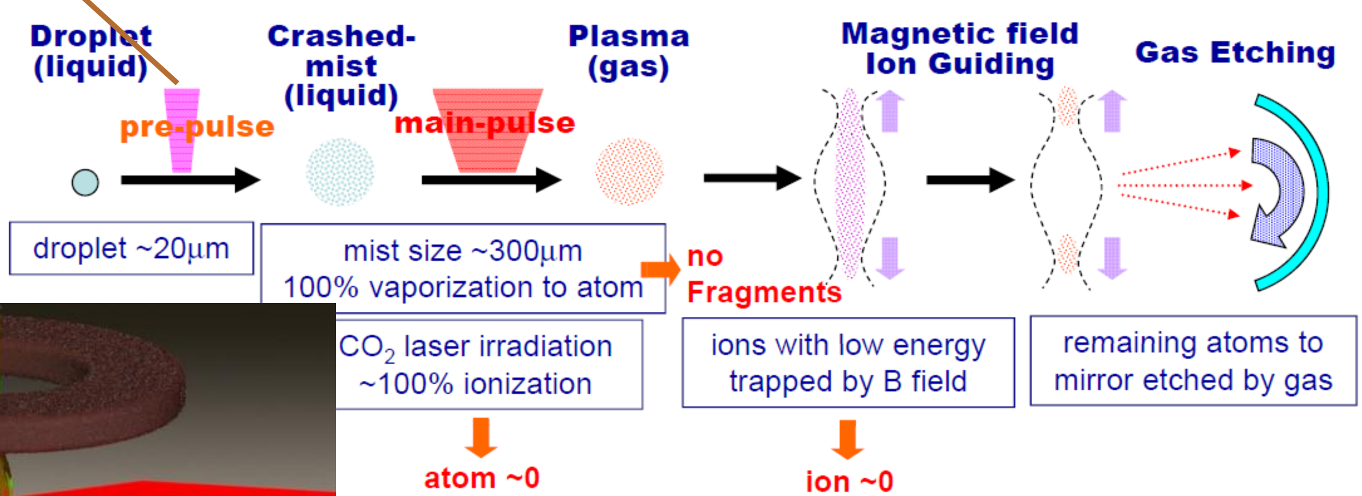
Pre-pulse Laser for High Volume Machine EUV/BEUV Lithography

GIGAPHOTON

Debris mitigation concept

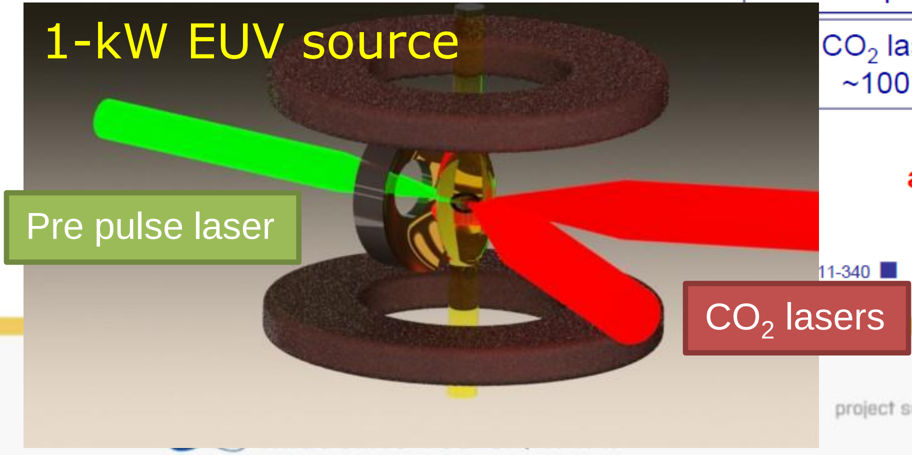
- Double pulse laser irradiation
- Magnet field is effective for guiding ions
- Gas etching

- Solid-state laser
- 3.3 mJ
- 150 kHz
- (500 W)
- <10 ps



KOMATSU

[8322-14] SPIE 2012 Advanced Lithography, February 14, 2012, P11



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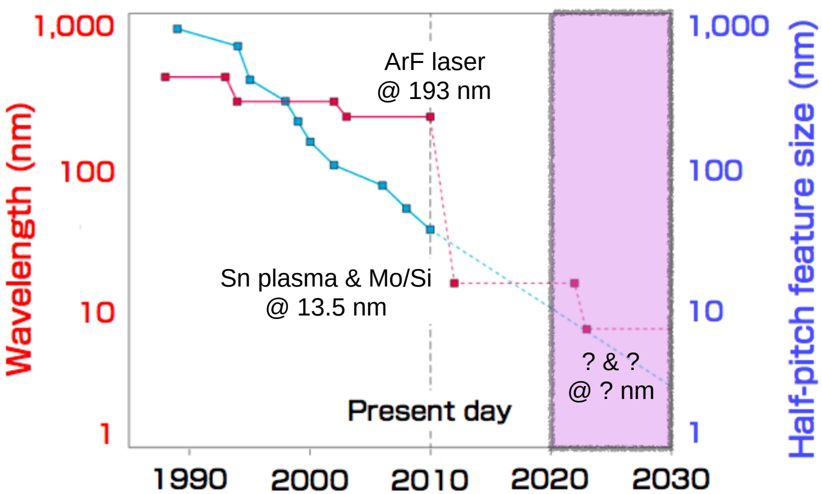
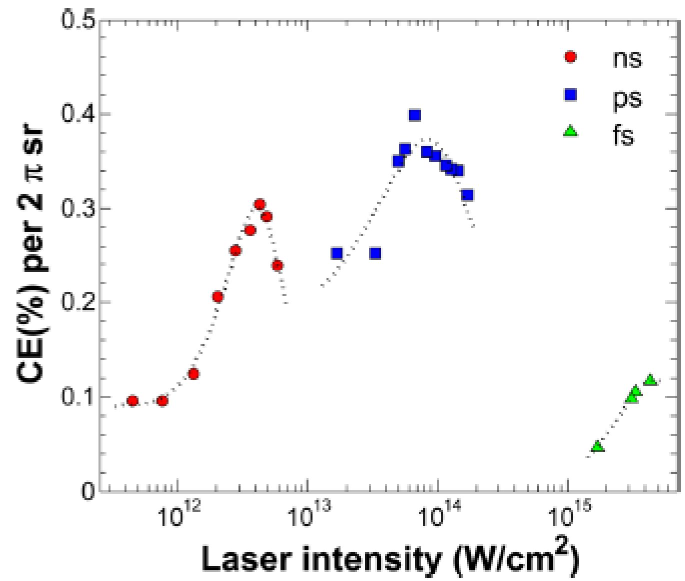
6.Xnm Beyond EUV (BEUV) Source

APPLIED PHYSICS LETTERS **100**, 061118 (2012)

Optimizing conversion efficiency and reducing ion energy in a laser-produced Gd plasma

Thomas Cummins,[1,a)] Takamitsu Otsuka,[2] Noboru Yugami,[2,3] Weihua Jiang,[4] Akira Endo,[5] Bowen Li,[1] Colm O'Gorman,[1] Padraig Dunne,[1] Emma Sokell,[1] Gerry O'Sullivan,[1] and Takeshi Higashiguchi[2,3]
[1]*School of Physics, University College Dublin, Belfield, Dublin 4, Ireland*
[2]*Department of Advanced Interdisciplinary Sciences, Center for Optical Research and Education (CORE), and Optical Technology Innovation Center (OpTIC), Utsunomiya University, Yoto 7-1-2, Utsunomiya, Tochigi 321-8585, Japan*
[3]*Japan Science and Technology Agency, CREST, 4-1-8 Honcho, Kanagawa, Saitama 332-0012, Japan*
[4]*Department of Electrical Engineering, Nagaoka University of Technology, Kami-tomiokamachi 1603-1, Nagaoka, Niigata 940-2188, Japan*
[5]*Research Institute for Science and Engineering, Waseda University, Okubo 3-4-1, Shinjuku, Tokyo 169-8555, Japan*





For laboratory use
- Solid-state lase
- 100-200 mJ
- 1 kHz
- 1-100 ps

In-line Phase Contrast Imaging of A Biological Specimen

APPLIED PHYSICS LETTERS **92**, 131107 (2008)

In-line phase-contrast imaging of a biological specimen using a compact laser-Compton scattering-based x-ray source

H. Ikeura-Sekiguchi,[1,a)] R. Kuroda,[1] M. Yasumoto,[1] H. Toyokawa,[1] M. Koike,[1]
K. Yamada,[1] F. Sakai,[2] K. Mori,[3] K. Maruyama,[3,b)] H. Oka,[4] and T. Kimata[4]
[1]*National Institute of Advanced Industrial Science and Technology (AIST), Central 2-5, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan*
[2]*Sumitomo Heavy Industries, Ltd. (SHI), 2-1-1, Yatocho, Nishitokyo, Tokyo 188-8585, Japan*
[3]*Ibaraki Prefectural University of Health Sciences, 4669-2, Ami, Inashiki, Ibaraki 300-0394, Japan*
[4]*St. Marianna University School of Medicine, 2-16-1, Sugao, Miyamae-ku, Kawasaki City 216-8512, Japan*

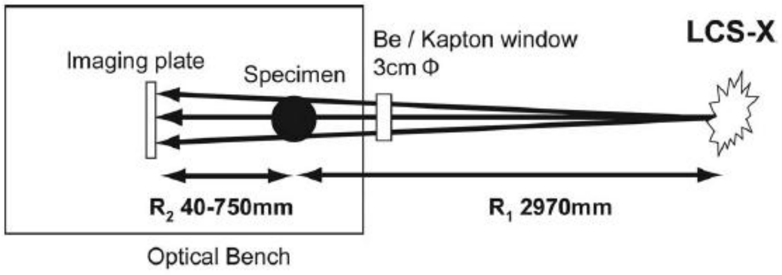


FIG. 1. Schematic drawing of in-line phase-contrast imaging using LCS x ray at AIST.

0.5-1 J, 1 ps pulse

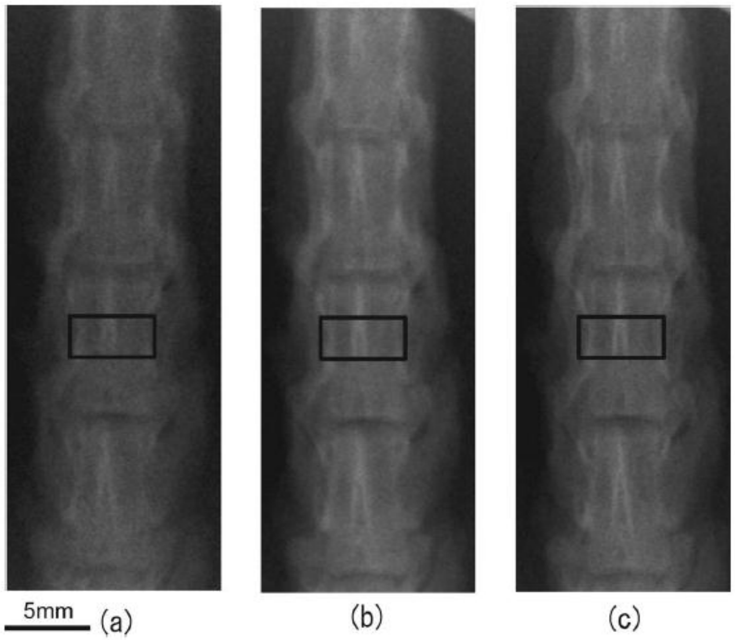
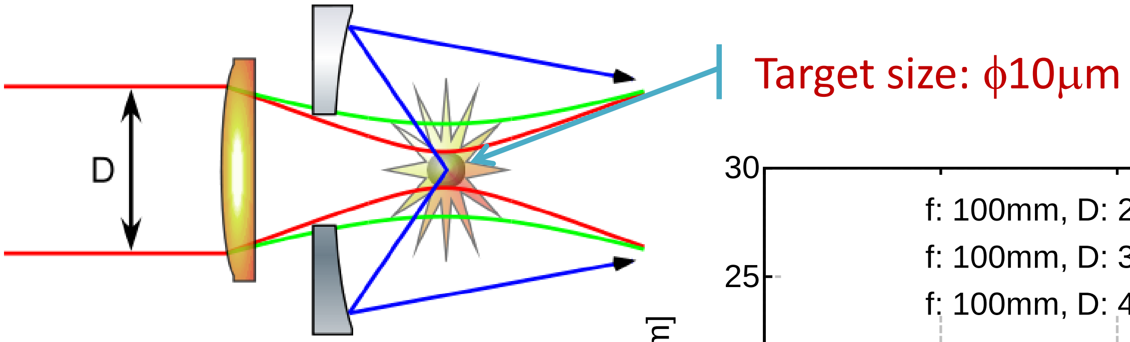


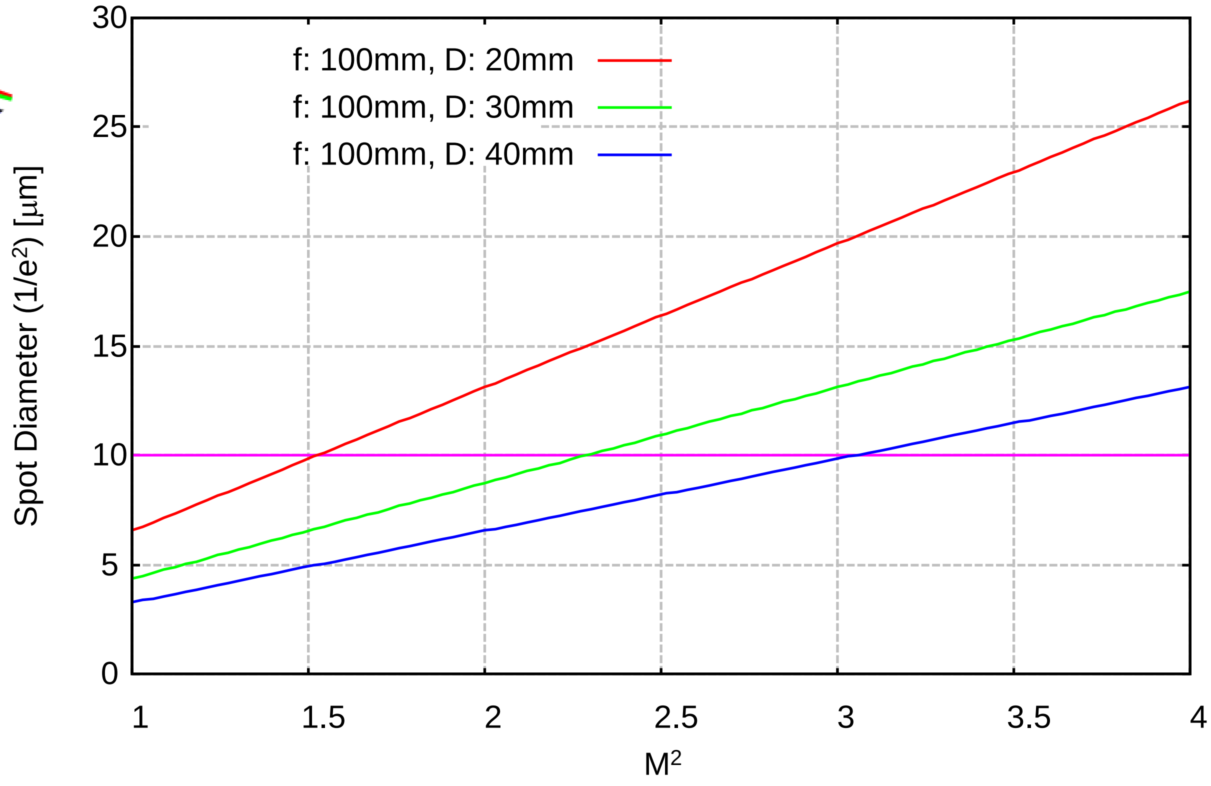
FIG. 2. Effect of increasing propagation (sample-to-detector) distance R_2 on images of rat lumbar vertebrae in frontal projection. Images were recorded using an LCS x ray using an energy of 30 keV: (a) R_2=40 mm, (b) R_2=200 mm, and (c) R_2=750 mm.

Exposure time: 1800 sec

Focusing Property of Driving Laser for EUV, BEUV, X-ray Pulse Generation

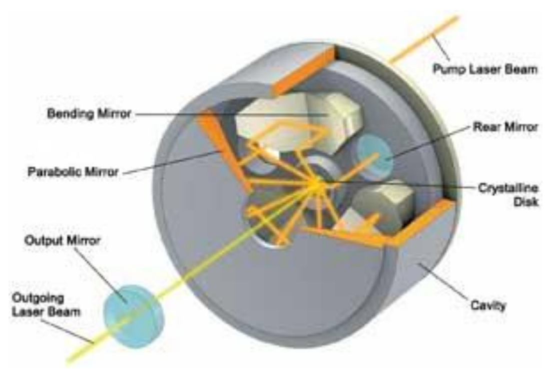


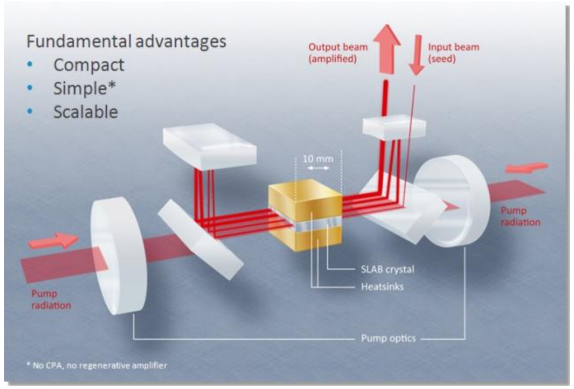
Target size: 10μm
Focal length of lens: f=100mm
- D=20mm
  M^2<1.5
- D=30mm
  M^2<2.3
- D=40mm
  M^2<3



High Energy Picosecond Pulse Sources

	Dual Thin disk Regen. (MPQ, 2012)	Single Thin disk Regen.[1] (MPQ, 2009)	Single Thin disk Regen.[2] (MBI, 2011)	Single Thin disk Multi-pass[3] (MBI, 2012)	Single Thin disk Multi-pass[4] (DESY, 2012)	Innoslab[5] (DESY, 2011)	Innoslab[5] (DESY, 2011)
Repetition rate [Hz]	1,000,000	3,000	150	100	10 (100kHz burst)	12,500	100,000
Pulse energy [mJ]	0.23	25	305	548	3560 (80 pulses)	20	2
Average output [W]	230	75	45.8	54.8	35.6	250	200
Pump energy [J]	CW	0.1	3.8	6.0	16.1	CW	CW
Pump power [W]	600	280	562.5	600	161.2	600	600
O-O Efficiency [%]	38.3%	26.8%	8.1%	9.1%	22.1%	41.7%	33.3%

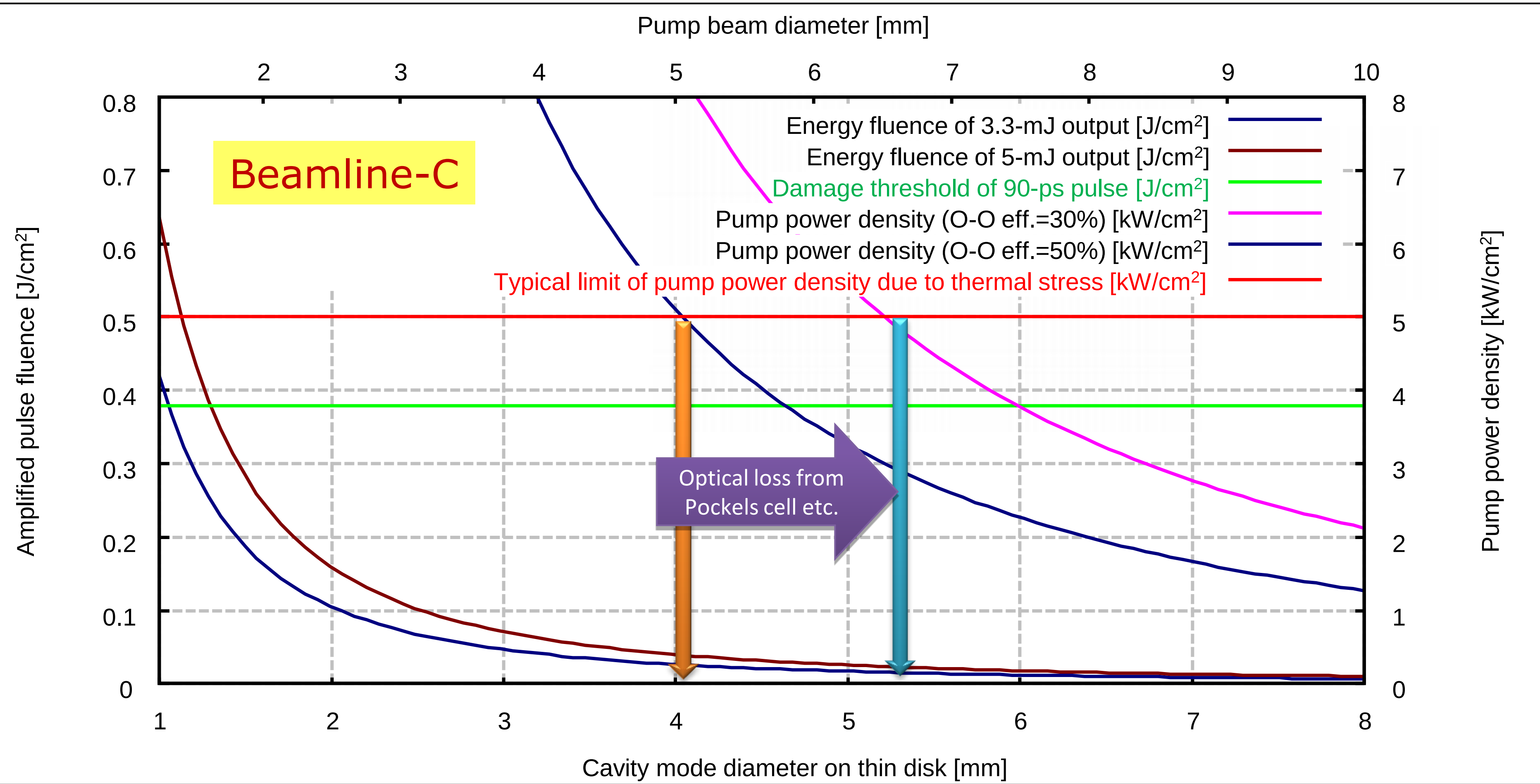




[1] T. Metzger *et. al.*, Opt. Lett. **34**, pp. 2123 (2009).
[2] H. Stiel *et. al.*, PTB Seminar EUV Metrology (2011).
[3] R. Jung *et. al.*, Disklaser Workshop (2012).
[4] M. Schulz *et. al.*, Opt. Express **20**, pp. 5038 (2012).
[5] M. Schulz *et. al.*, Opt. Lett. **36**, pp. 2456 (2011).

High energy +
High average power
= Challenging

Scaling Method of Thin Disk Laser for Fundamental-Mode Operation



Large diameter thin disk → Degradation of beam quality due to higher order optical phase distortion

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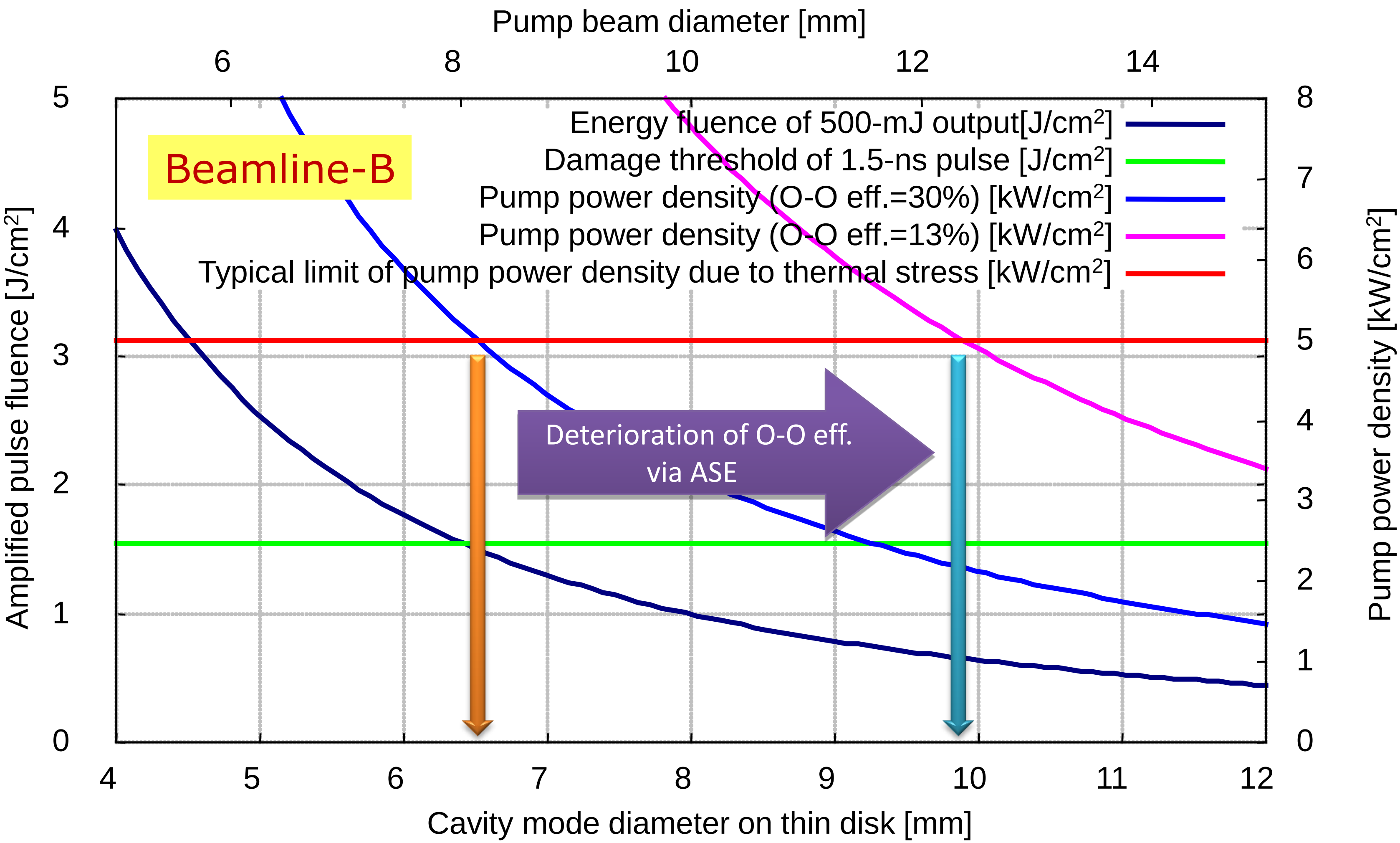
Scaling Method of Thin Disk Laser for Fundamental-Mode Operation



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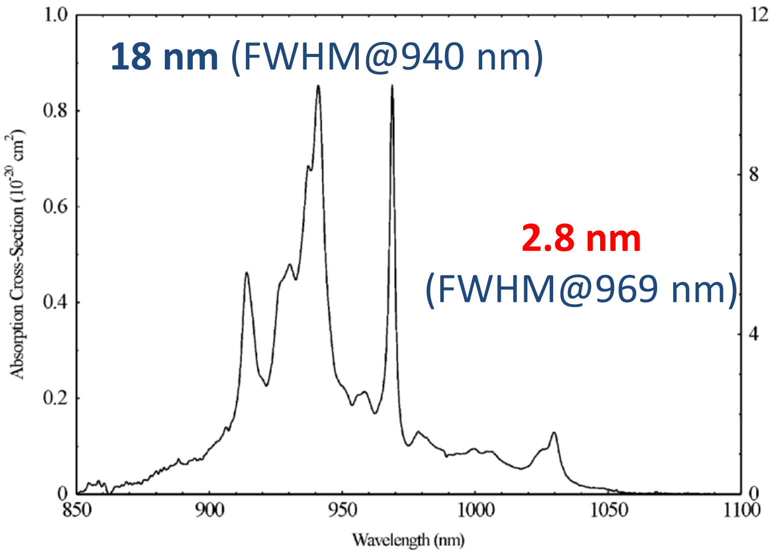
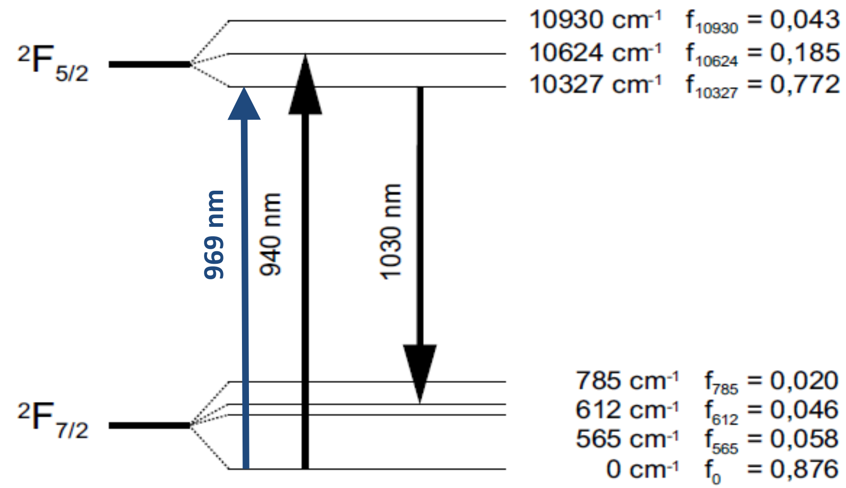
Improvement of O-O Efficiency via Zero-Phonon Line Pumping

hilase

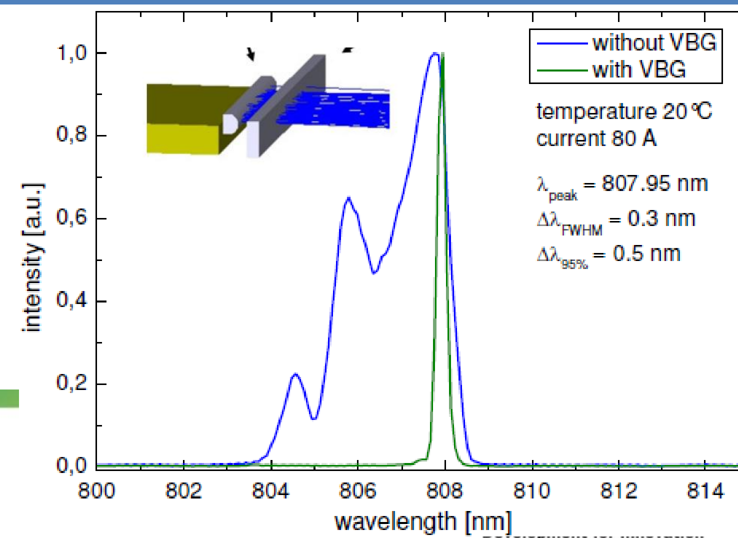




Advantages of zero-phonon line pumping

- Lower quantum defect
  - 8.7 % @ 940 nm
  - 5.9 % @ 969 nm
- Less heat generated in the gain medium
  - Smaller deformation of thin disk
  - Higher pump density

(ex.)VBG (Volume Bragg Grating) installed narrowband laser diode

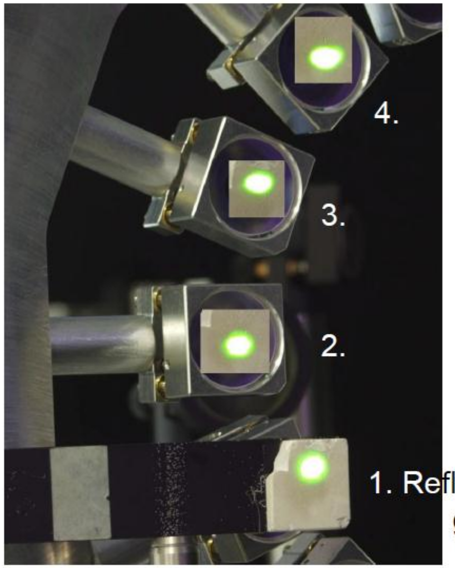


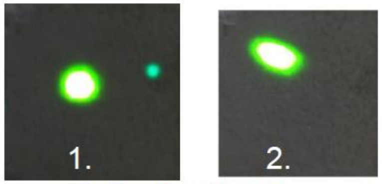
Beam Distortion Due to The Deformation of Large Size Thin Disk

Tests of soldered 25mm disks

Max-Born-Institut

Spherical shape not yet as reproducible as with gluing

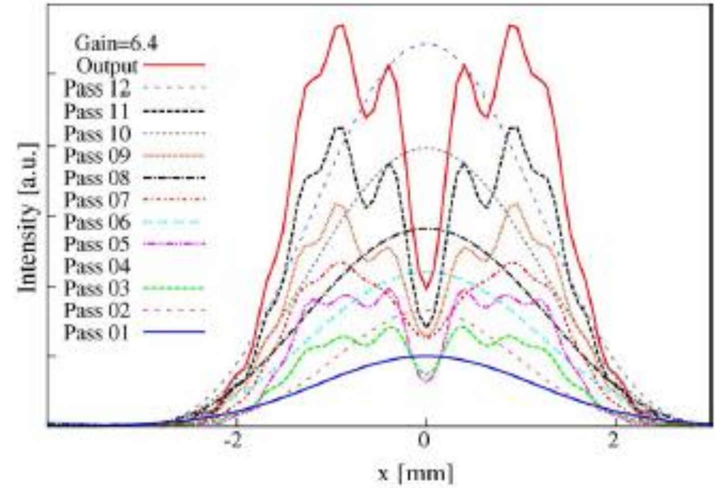




Reflection from
soldered Yb:YAG disk

1. Reflection from
glued Yb:YAG disk

Disklaser Workshop, Dausinger & Giesen, 15. Mai 2012 - 18 -

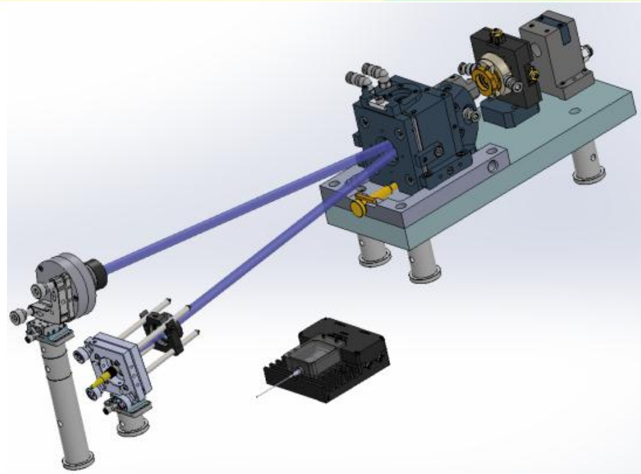


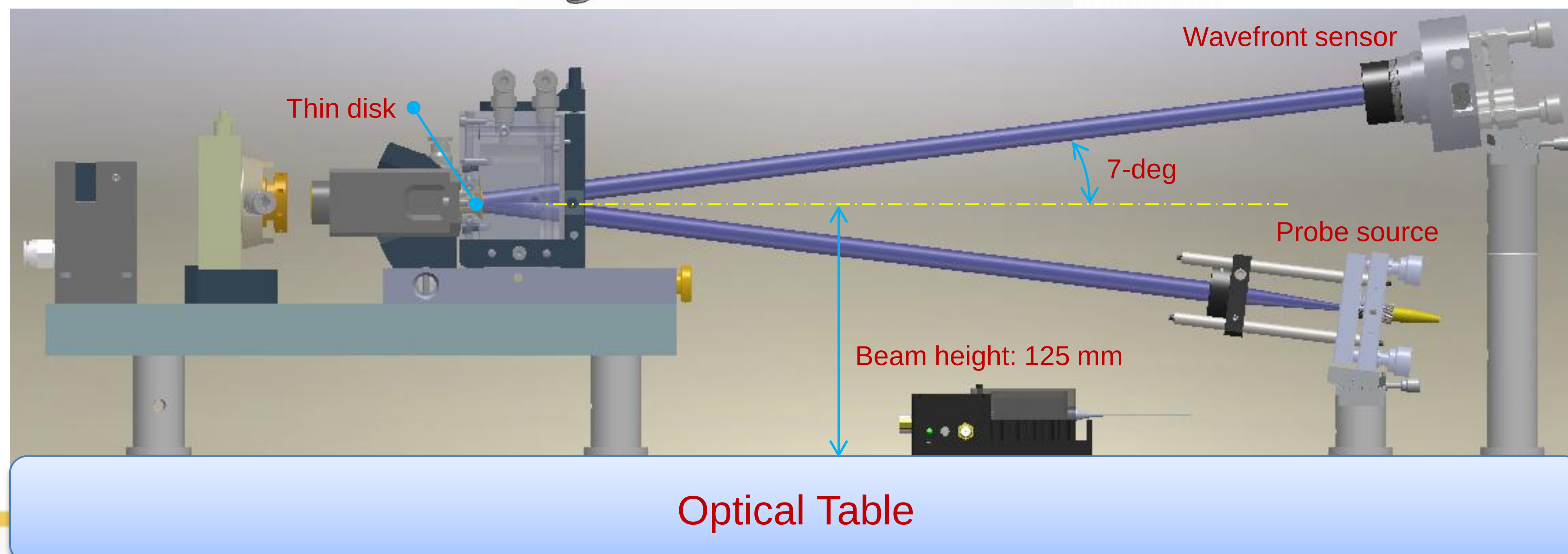
Bifurcation of beam profile from thin disk multi-pass amplifier[2]

The real time measurement of thin disk deformation is the key issue.

[1] R. Jung *et. al.*, Disklaser Workshop (2012).
[2] A. Antognini *et. al.*, IEEE J. Quantum Electron. **45**, pp. 993 (2009).

In-situ Measurement of Thin Disk Deformation Using Wavefront Sensor





RP1 Group

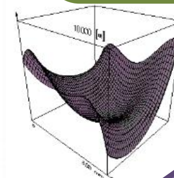
P. Severova

Analysis by simulations
Exploring improvements

Comparison with numerical model

T. Miura

Evaluation of thin disk deformation ,gain (ASE) etc.



Suggestions for improvement

Real-time measurement

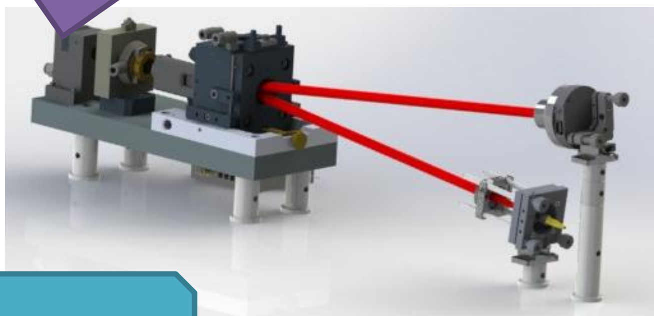
M. Chyla

M. Smrz

O. Novak

High energy Thin disk
Regenerative amplifier
Ring amplifier

A. Endo (RP1 leader)



Applications (EUV BEUV HHG …)

Fundamental Research Has Been Started

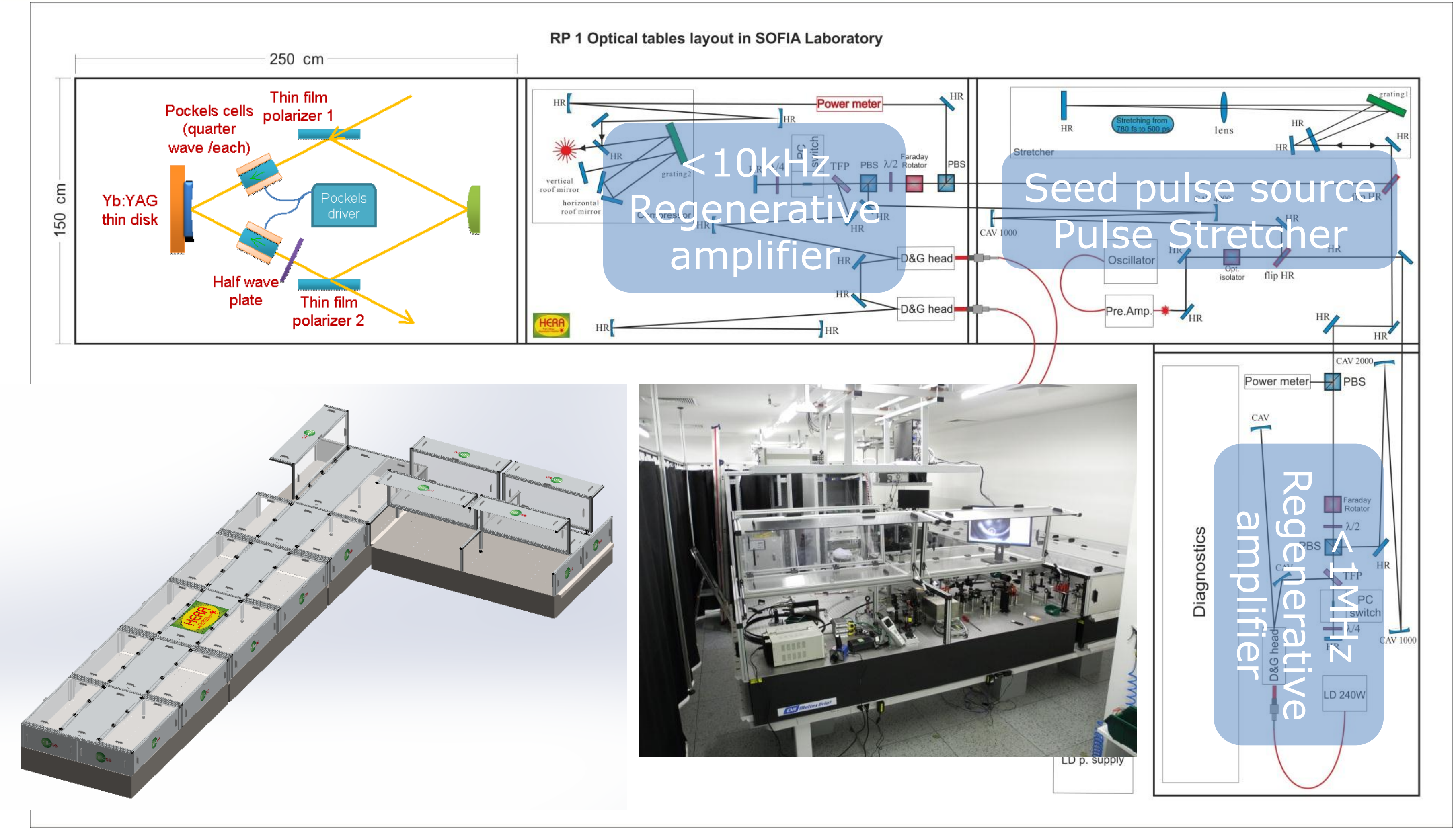
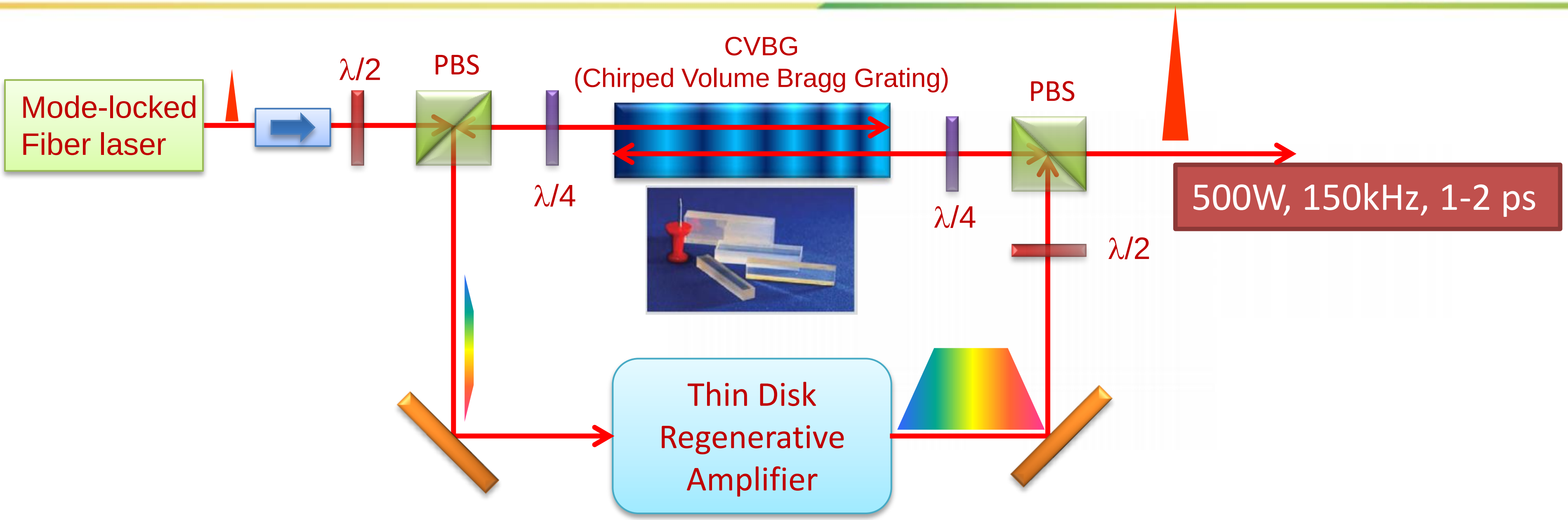
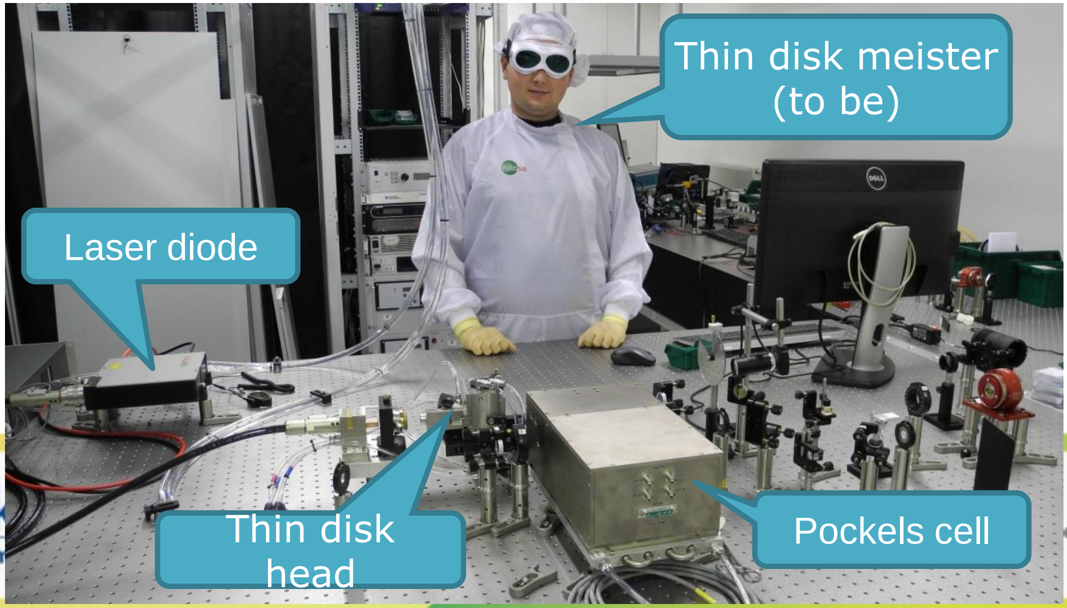
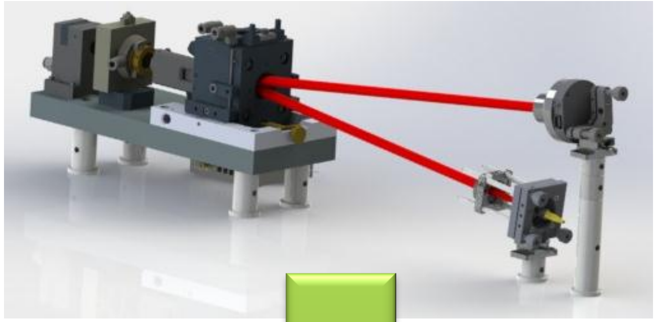


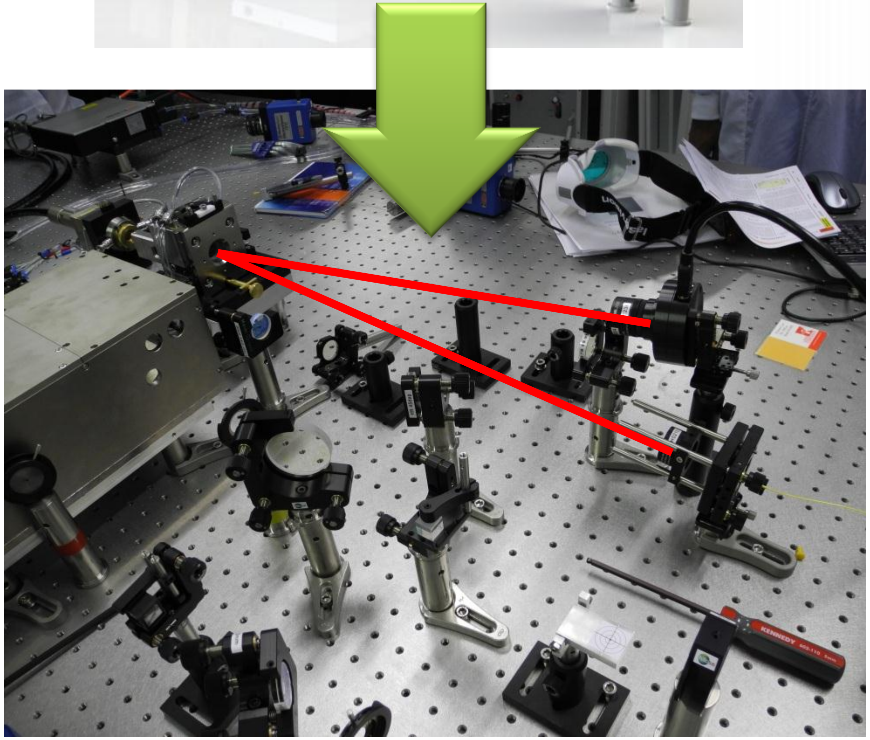
Table-top High Power Laser Source in HiLASE



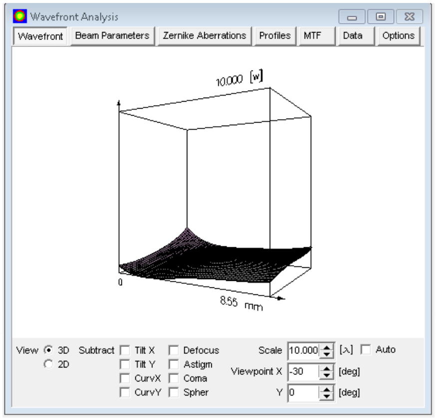


In-situ Measurement of Thin Disk Deformation

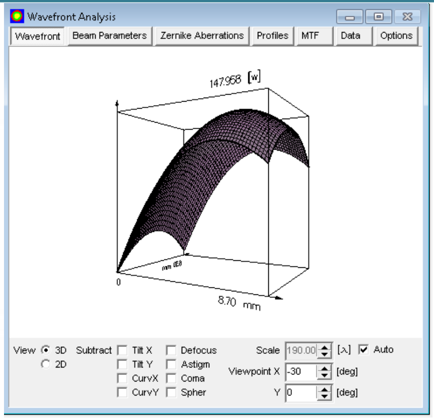




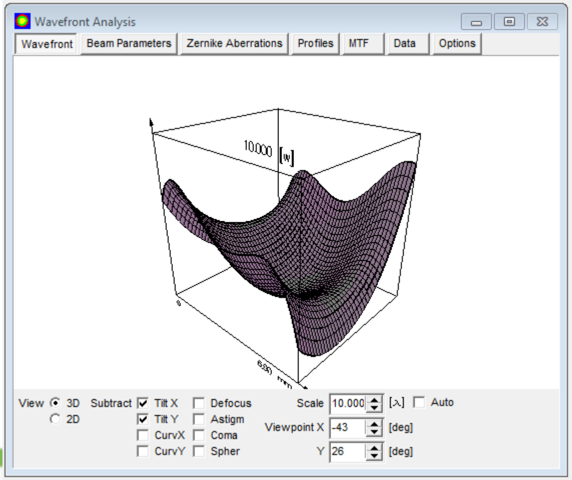
Wavefront from flat



Wavefront from concave mirror (R=400mm)



Wavefront from thin disk



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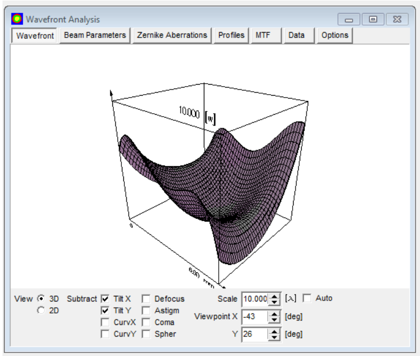
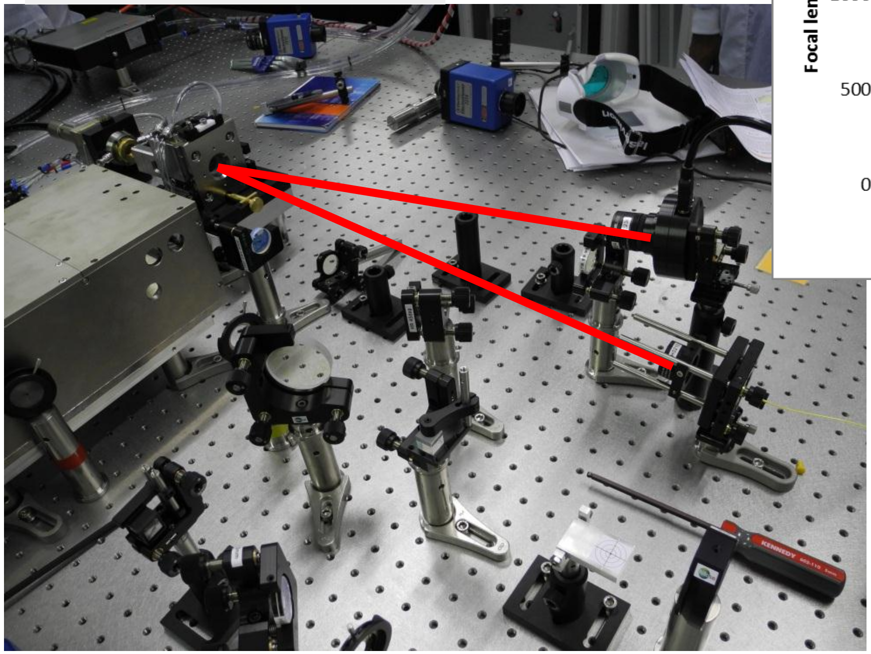
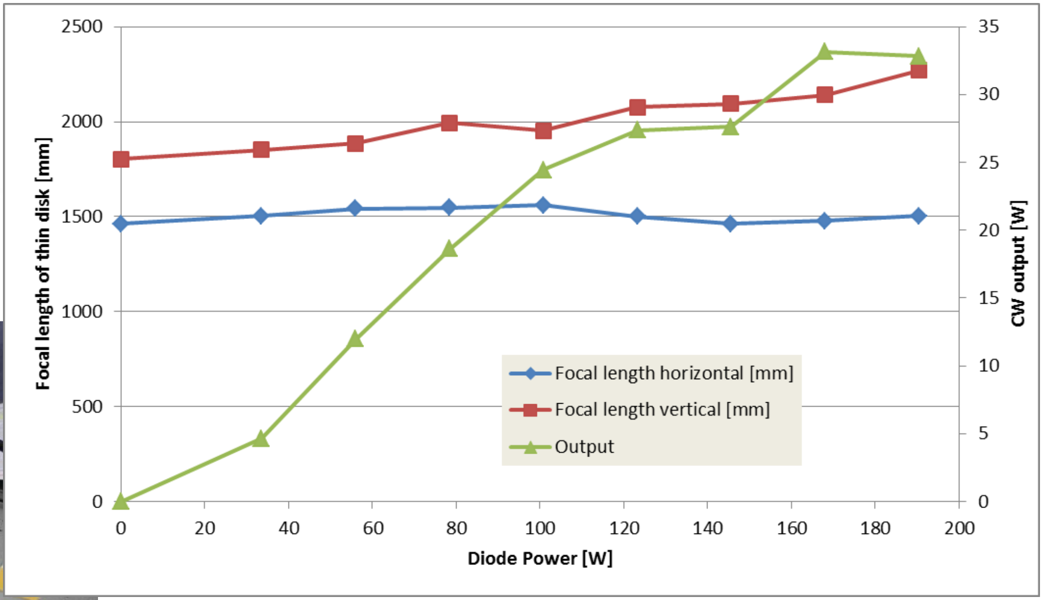
Preliminary Result of Thin Disk Deformation Measurement







Summary

- Introduction of the HiLASE Project
- Overview of the beam lines in RP1
- Design concepts of beam line B & C
- Preliminary result of thin disk deformation under the lasing operation
- High energy / high repetition rate amplifiers are under the construction
  - End of this year
    - 100mJ, 1kHz, 1-2ps
    - 1mJ, 100kHz, 1-2ps